VIII. *An Experiment proposed for determining, by the Aberration of the fixed Stars, whether the Rays of Light, in pervading different Media, change their Velocity according to the Law which results from Sir* Isaac Newton's *Ideas concerning the Cause of Refraction; and for ascertaining their Velocity in every Medium whose refractive Density is known. By* Patrick Wilson, *A. M. Assistant to* Alexander Wilson, *M. D. Professor of Practical Astronomy in the University of* Glasgow; *communicated by the Rev.* Nevil Maskelyne, *D. D. F. R. S. Astronomer Royal.*

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UPON the supposition that the refraction of light is caused by a certain action of grofs and fenfible bodies upon it, Sir ISAAC NEWTON has demonftrated, that the fines of incidence and refraction, when the rays pafs out of one medium into another of different denfity, muft always be in a conftant ratio. This conftancy of the ratio of the fines is agreeable to an univerfal experience, and has been called the law of refraction. Upon the fame grounds he has alfo demonftrated, that the velocity of the rays muft be greater in the more refracting medium in the inverfe ratio of the fines. Of this property of refraction, however, we have hitherto had no evidence in the way of experiment. The ideas entertained by Sir ISAAC NEWTON, from which this property has been deduced, though they confefs their great author, by a moft beautiful fimplicity,

and

and by a very ftriking agreement with fact, have yet been
deemed by fome perfons as not perfectly authentic. His contem-
porary LEIBNITZ and others have attempted demonftrations of
the law of refraction from principles very different, and which
do not lead to the opinion of the acceleration of light in the
more refracting medium. At prefent it is propofed to point
out a method of determining experimentally the law of the
variation of the velocity of light, according to the change of
the medium. If obfervations fhall fhew this law to be agreea-
ble to Sir ISAAC NEWTON's conclufions, we fhall then have a
very ftrong additional evidence in favour of his principles. If,
contrary to the moft probable iffue of the experiment, fome
unfufpected law fhould be difcovered, we muft, according to
the rules of induction laid down by that great mafter in phi-
lofophy, fo far reftrict our general conclufions, and accommo-
date our ideas to the real condition of things.

The method of experiment at prefent alluded to is, that of
obferving the aberration of the fixed ftars with a telefcope filled
with a denfe fluid, fuch as water, or any other equally limpid
and of greater refraction, fitted to bring the rays to a focus by
the furface of the medium oppofed to the object having a pro-
per degree of convexity. It is enough at this time to fuggeft a
general notion of the inftrument, and we now proceed to ex-
plain in what manner it can affift us in the prefent inquiry.

Since aberration, taken in its enlarged fenfe, depends on the
relative velocities of light and of the telefcope, if the rays
were really to move much fafter or much flower in an unufual
telefcope of this kind, it feems to follow, that the quantity of
aberration given in thefe circumftances, compared with Dr.
BRADLEY's angle, would certainly indicate the new rate of ve-
locity. Such an inference would certainly be juft, and it is

upon

upon thefe grounds that we propofe to inquire into the velocity
of the rays, as they move forward in denfe media fo applied to
telefcopes. Granting, however, for the fake of argument,
that light moves down through fuch an unufual telefcope with
an increafed velocity fuited to the refractive denfity of the me-
dium, it will by no means happen, that the aberration will be
changed on that account. This propofition, which at firft view
may appear paradoxical, and even contradictory to what has
been affirmed above, is however not the lefs certain, and may
ferve to fhew, what caution is fometimes requifite in applying
general principles to particular cafes : for it fhall be proved,
that the aberration in fuch a telefcope will precifely agree with
that of Dr. BRADLEY's only in the cafe of the rays moving
fwifter in the watery medium than in air, in the ratio affigned
by Sir ISAAC NEWTON, and that this famenefs of aberration
will itfelf be a proof of light being fo accelerated within the
telefcope.

In the illuftrations which follow, the reader is fuppofed not
to be wholly unaccuftomed to the diftinctions betwixt abfolute
and relative motion, as this will prevent repetitions and all
unneceffary prolixity.

Let ABC (fig. 1.) be the fpherical refracting furface of fuch
a telefcope as has been defcribed, and let the telefcope be fup-
pofed to be at reft, or the velocity of light to be infinite with
refpect to that of the earth, and let GBMF be a line drawn from
a ftar at G, in the pole of the ecliptic, through the center M
of the refracting furface ; the image of the ftar will be formed
fomewhere, as at F, in the line BF; and here the interfection
of the crofs wires made ufe of in obferving muft be placed.
It is evident, that the ftar will be feen in its true direction FG ;
and we muft conclude that to be its true direction, becaufe we
know

know that the ray GBF paffes into the medium without being refracted by it, and BMF would be confidered as the axis of the telefcope.

Now let the fpherical refracting furface with its wires, or the unufual telefcope be carried laterally with the motion of the earth towards Q. Conceive GBF to be a line not partaking of this lateral motion, which at any particular moment paffes thro' M, the center of convexity. Along this line fuppofe one of many rays to pafs from a ftar fituated in the pole of the ecliptic. Then will all the contemporary light of this pencil of parallel rays be made to converge fo as to meet in a focus fomewhere in the unrefracted ray BF. Let F therefore be the point in abfolute fpace where the image of the ftar is fo formed. Let the parallel motion of the telefcope, whofe refracting fpherical furface is ABC, be in the direction of HF, and take FD to FB as the lateral velocity of the telefcope to the velocity of light in air, and join BD: then it is manifeft, that BD will be the pofition of a telefcope fuch as Dr. BRADLEY's, when the image of the ftar is formed in the axis BD, and that IBG, or its equal FBD, will be the angle of greateft aberration.

Moreover, the velocity of the rays as they proceed to the focus F, after refraction at the furface ABC, being fuppofed the fame as in air, it is evident, that the line DML drawn through D, and through the center of convexity M, muft give the pofition of the axis of this kind of telefcope, when the image of the ftar is formed there: for, by hypothefis, the image is formed in F in abfolute fpace, and fince BF is fuppofed to be to FD, as the velocity of light within the medium to the lateral velocity of the telefcope, the point D of the axis DL will arrive at F, when the rays arrive there to form

the image. And the obferver not knowing, or at prefent not taking account of, the lateral motion of the telefcope, will fuppofe, that the line LMD joining the image of the ftar and the center of convexity M is the true direction of the ftar; juft as before he concluded, that FMBG would be the direction of the ftar when the lateral motion of the telefcope was fuppofed to be nothing. Hence it is evident, that the interfection of the crofs wires, made ufe of in obferving, muft now be placed at D; or elfe, if thofe be ftill ufed that were before fuppofed to be at F, the refracting furface ABC with the line or axis BF muft revolve about the center M till the vertex B comes to L and the crofs wires F to D.

In like manner, if the velocity of the rays were increafed after refraction at the fpherical furface in any ratio, as that of DF to EF, the refraction continuing the fame, then EMO drawn through the center of convexity would now give the pofition of the axis of the telefcope neceffary for receiving the image formed at F. For the fpace defcribed by the rays in paffing downwards to the focus, in this cafe and the former being equal, the times of their converging at F will be reciprocally as the velocities, or as EF to DF. But, on account of the equable lateral motion of the telefcope, DF and EF will be as the times of the points D and E arriving at F: therefore, in the laft cafe, the interfection of the crofs wires fuppofed at E will meet the image at F, and accordingly the ftar will be feen in the axis.

Fig. 2. From what has been faid it will appear, that if DF be taken to EF, as the fine of incidence to the fine of refraction peculiar to the medium which fills the telefcope; then, from the property of the focus, we fhall have this proportion, *viz.* BF : FM :: DF : EF. Hence the line EMO paffing

through

through M muſt be parallel to DB; but DB, as before, de-
notes the poſition of Dr. BRADLEY's telefcope, when the aber-
ration of the ſtar is at its maximum, and EMO parallel to it,
denotes the poſition of the water telefcope, at the ſame time,
upon the ſuppoſition that the velocity of the rays without and
within be as EF to DF, or inverfely, as the ſines of incidence
and refraction peculiar to water. Here then we difcover what
muſt be the law of variation as to the velocity of the rays,
provided that the aberration given by fuch a telefcope ſhall
come out the ſame with that found by Dr. BRADLEY. It is the
very ſame which follows from the Newtonian principles: for
from the manner of obſerving, the angle of aberration is
always determined by the poſition of the telefcope neceſſary
for having the image formed ſomewhere in the axis.

But ſuppoſing that in the courfe of obſerving with fuch a
telefcope, the aberration ſhould come out different from what
has already been aſcertained by Dr. BRADLEY, it may next be
enquired, how from the difference given the velocity of light
within the telefcope is to be deduced.

Fig. 3. Imagine then fuch a telefcope actually to give FMD
as the greateſt angle of aberration, and let this be ſuppoſed
greater than that of Dr. BRADLEY's, which, for example, let
be FME. From what has been already ſaid, the velocity of
light correfponding to this laſt mentioned angle, is deducible
from the known refraction of the medium which fills the tele-
fcope; and, by conſtruction, the velocity correfponding to
FMD, the angle given, muſt be to the former inverfely as the
tangents of thefe angles. From this confideration we have the
following analogy for finding the velocity correfponding to
whatever difference there may be obſerved between the two
aberrations at prefent alluded to. The rule in all cafes muſt be;

" as

" as the tangent of the obferved angle is to the tangent of the
" Bradleyan angle, fo is the velocity of light deducible from
" the hypothefis of the obferved angle being the fame with
" that of Dr. BRADLEY to the velocity fought." It has already
been fhewn, how the former of thefe velocities can be univerfally
afcertained, from the known refraction of the medium which
is taken to fill the telefcope, and therefore the laft term of the
above proportion, which is the velocity fought, is thereby
given.

Fig. 2. In a telefcope of this kind it will not have efcaped
notice, that the ray BF, which, on account of its paffing to
the focus unrefracted, may be called the axis of the pencil,
can never be found in the axis of the telefcope EO, except at
the focus F, where D and F meet. That ray, however, OP,
parallel to BG, which falls obliquely on the axis of the tele-
fcope EO, will continue to pafs along it after refraction, and
for that reafon it may be called the relative axis of the pencil.

This will appear, by confidering that the particle of light,
which at any moment is refracted at the vertex O of the fpheri-
cal furface, is found by hypothefis in the axis a fecond time,
when it meets the cotemporary light at the focus. But fince
both the motion of the axis and of the particle is uniform and
rectilinear, the former cannot be found in the latter at two
different times, without being found in it continually during
the whole interval. In like manner, a part of every other ray
from the ftar, which fucceffively falls upon the vertex, muft
move relatively along the axis after refraction : and thus a con-
ftant fucceffion of thefe particles conftitute a vifual refracted
ray, whofe relative path muft always be in the axis OE.

All that has been fhewn concerning the telefcope already
confidered, will receive ftill further illuftration, by tracing the

motion

motion of this particular refracted ray till it arrives at the focus. This way of viewing the subject will also render the reasoning more general, and make it apply to telescopes when the dense fluid within is supposed to be confined by object-glasses of any figure. But in order to this, it will be convenient to premise, and briefly to demonstrate, what shall afterwards be referred to by the name of

PROP. A.

Fig. 4. If any very small body or particle of light as it moves uniformly in the absolute path SB, has passed relatively along a part of the line CD, which advances equably and parallel to itself in the direction DK; and if at any instant the absolute path of the particle be changed into any other, as BR; I say, it will still pass relatively along the moving line, provided its velocity now be to its former velocity as the sine of the angle DBF to the sine of the angle DBR; these being the angles which the moving line BD makes with BF and BR the absolute path or direction of the particle in the two cases.

The construction of this figure is so simple, that it is unnecessary formally to point it out. Since, by hypothesis, the velocity of the particle along BR is to its former along BF as the sine FZ to the sine RT; or, on account of similar triangles, as DF to IR, and, on account of parallels, as DF to DW, it follows, that the time of its describing BR now, is to the time of formerly describing its equal BF, as DW to DF. But the line BD advancing with a uniform motion, the time of its arriving at W is to the time of its arriving at F, also as DW to DF. Therefore, when the particle arrives at R, the point D of the moving line will have arrived at W, and WRP will be its position. Hence the particle at that moment must be found in the intersection R of this line, with its absolute path BR. In the

fame manner it may be fhewn, that at any other time the par-
ticle will be found in the interfection : it, therefore, from the
time of its direction being changed at B, muft pafs relatively
along the moving line as before.   By a fmall alteration in the
conftruction it may be fhewn, that if the abfolute path had
been fo changed at B as to have augmented the angle FBD, ftill
the particle would have moved relatively along DB, provided its
velocity after had been to its velocity before as the fine of FBD
the firft angle to the fine of the increafed angle.

   To apply, therefore, this propofition to the prefent invefti-
gation, let DB be conceived as the axis of a telefcope perpen-
dicular to the fpherical furface of a refracting medium which
accompanies it in its lateral motion, SB the abfolute path of a
particle of light which had paffed relatively along DB pro-
duced, till its arrival at B, and BR its abfolute path within the
medium of the telefcope.   Then it is evident, that FBD, or its
equal CBS, will be univerfally the angle of incidence, and
RBD the angle of refraction.   Hence, by prop. A. that ray
of the parallel pencil which is refracted at O, the vertex of
the fpherical furface in fig. 2. muft ftill pafs relatively along the
axis, provided the velocity within the telefcope be to its former
in air, as the fine of incidence to the fine of refraction.   But
the image of the ftar being produced by the meeting of all the
contemporary light, will confequently be found in the axis,
which, by hypothefis, deviates from the true place of the ftar
by the fame quantity as Dr. BRADLEY's angle ; fo that in this
way of confidering the matter, the fame thing refults which
was formerly fhewn in regard to a telefcope fo conftructed.

   By prop. A. it is alfo manifeft, that whatever number of re-
fractions that ray which falls upon the extremity of the axis
fuffers in pervading object-glaffes of any figure, or even denfe
media,

media beyond the object-glafs if bounded by tranfparent planes
to which the axis produced is perpendicular, yet if the veloci-
ties and refractions fo correfpond, ftill the ray in queftion will
pafs relatively along the axis till it meet the reft at the focus :
for here the refracted ray in the firft medium becomes the inci-
dent ray in relation to its path in the fecond, and this in its
turn becomes an incident ray in relation to its path in the third
medium, &c. and therefore by the prop. A. can never deviate
from the moving axis whatever be the refractive denfity of the
media, or however thefe are difpofed in the order of fucceffion.
And fince, by Sir ISAAC NEWTON's theorem, the ratio of the
fine of incidence to the fine of refraction in the paffage of a
ray out of one medium into another, is compounded of the
ratio which the former has to the latter in the paffage of that
ray out of the firft medium into any third, and of the ratio of
the former to the latter in the paffage of the fame ray out of
the third medium into the fecond, &c. it follows, that if the
velocities be related to the degree of refraction as before men-
tioned, the ray in the laft denfe medium will, notwithftanding
any number of previous refractions by glaffes, &c. have the
fame final velocity that would have been acquired on its paffing
immediately out of air into that medium.   This being the cafe,
it appears, that though the intervention of an object-glafs may
fhorten the focal diftance of fuch a telefcope, yet it will not
difplace the image nor alter the rule of inferring the final velo-
city of the rays in the denfe medium from the aberration given ;
at leaft when this is fuppofed to be the fame with Dr. BRADLEY's.

Fig. 3. But further, if the aberration of fuch a telefcope
fhould differ from the Bradleyan one, and give, for example,
the angle OMB, ftill the ray PO, which falls on O the vertex,
muft be confidered as an incident ray, which, after refraction,

paffes

paffes along the axis. By prop. A. therefore, the velocity of the ray, whatever this may be after refraction, muft be to that velocity by which it would have moved relatively in the axis, fo inclined to its path, previous to the refraction, inverfely as the fines of incidence and refraction. Now this being duly confidered, it will be found that the velocity within the medium, correfponding to this fuppofed aberration, or the abfolute velocity within the medium, muft be to the velocity within the medium correfponding to the Bradleyan aberration, inverfely as the tangents of thefe two angles : for let V and v exprefs the velocities before and after refraction correfponding to the Bradleyan angle, and X and x the velocities before and after correfponding to the fuppofed uncommon angle, x being the actual velocity after refraction ; then, becaufe by prop. A. the antecedent is to the confequent, in both cafes, in the fame ratio, *viz.* as the fine of refraction to the fine of incidence, it will be $V : v :: X : x$, and therefore $V : X :: v : x$. But from the nature of the aberration V muft be to X (this fuppofititious velocity before incidence) inverfely as the tangents of the angles of the two aberrations. This therefore muft be the ratio of v to x. But v is given as before fhewn ; therefore x the velocity within the medium correfponding to the fuppofed obferved aberration is alfo given, and by the fame rule as was found formerly in the cafe of the firft telefcope.

What has been at prefent advanced is unconnected with any hypothetical notions concerning the rays or the caufe of refraction. Light has been confidered only as fomething which moves uniformly from one place to another, and which is always refracted according to a known law. The firft of thefe properties has been put beyond all doubt by the obfervations of Dr. BRADLEY and Mr. MOLYNEUX ; and it is has been long known that the laft is quite agreeable to experience.
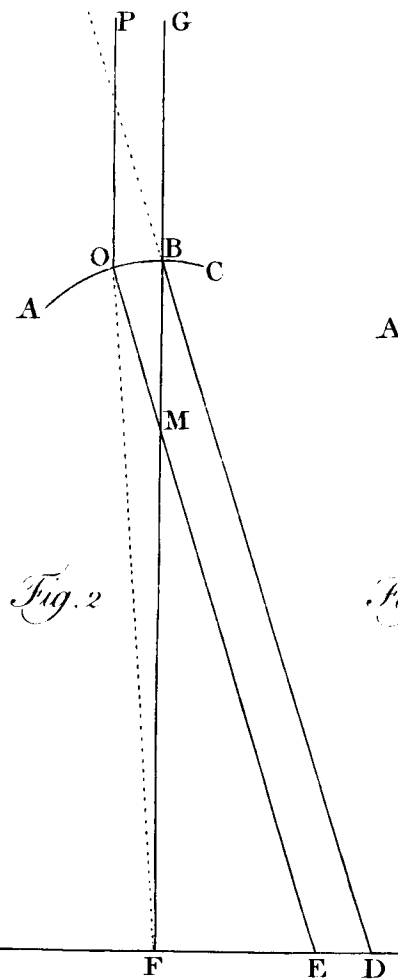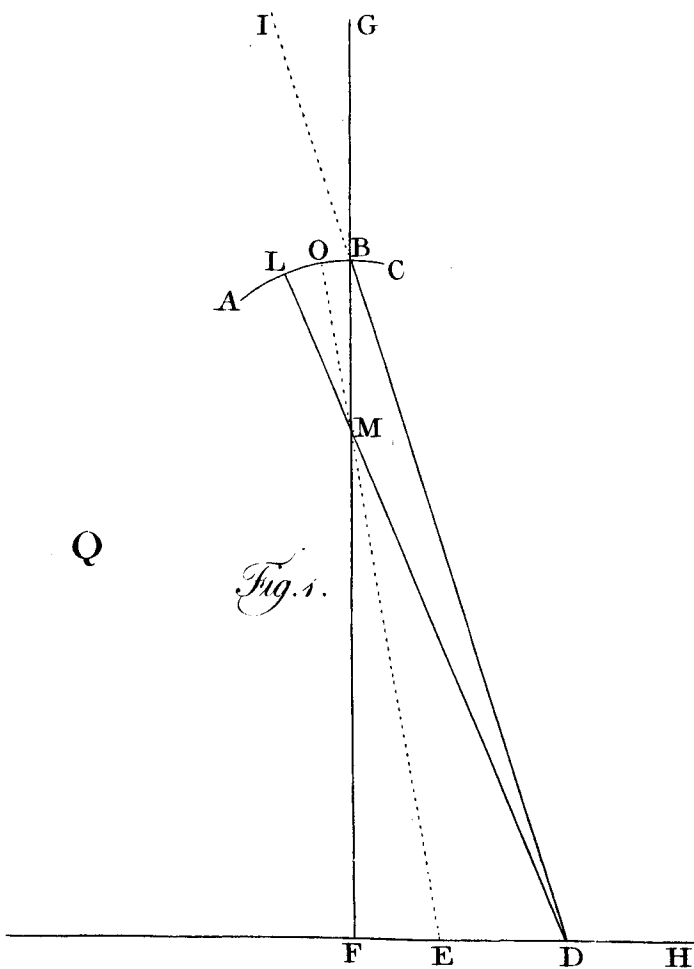
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It has indeed always been taken for granted, that the velocity of the ray which paſſes through the center of convexity, repreſents the common velocity of all the contemporary light of the converging pencil. This may perhaps be reckoned a circumſtance of which we have no proof. But it muſt be conſidered, that if the rays of light, after being variouſly bent towards the focus, were no longer to move with the ſame common velocity, the image formed at the focus of Dr. BRADLEY's teleſcope, would be elongated in the direction of the aberration. Thoſe who have attended to this ſubject will be at no loſs in diſcerning the reaſon of this. The extent of that lengthened image would depend upon the difference of velocity which would obtain among the converging rays, and would probably increaſe according to the largeneſs of the aperture of the object-glaſs. But ſuch a phenomenon being contrary to experience, it follows, that the unequal bending of the rays does not give them unequal velocities, whilſt moving in the ſame medium. This is another property with regard to the motion of light which may be conſidered as proved experimentally by Dr. BRADLEY's obſervations, and which doubtleſs would have occurred to him if he had had occaſion to trace the refraction of a pencil of parallel rays at the object-glaſs of his teleſcope.

To conclude : in bringing this queſtion concerning the velocity of light to the iſſue of an experiment, that fluid would doubtleſs be moſt proper for the teleſcope which abſorbs the feweſt rays, and poſſeſſes the greateſt refractive denſity, and which at the ſame time is not liable to generate air-bubbles. To compenſate for the unavoidable loſs of light, which by Mr. CANTON and Dr. PRIESTLEY's experiments is found to be conſiderable in ſuch caſes, it perhaps may be neceſſary to uſe an achromatic

achromatic object-glafs for the fake of a large aperture, and of fuch a figure as to fhorten the focal diftance as much as the obfervations of fuch a fmall angle can admit of. Some contrivance too will be requifite to keep the whole fpace between the object-glafs and the eye-glafs always full, notwithftanding the expanfions and contractions of the confined fluid by heat and cold, or its wafte by evaporation.

It might prove a very confiderable abridgement of the neceffary apparatus, if this kind of telefcope could be connected with the common telefcope of a mural quadrant, or zenith fector, and their axes made perfectly parallel by previous obfervations of a proper terreftrial object. But as there would be fome room for apprehending that the exact adjuftment of the axes might be affected in raifing the telefcopes afterwards for celeftial obfervations, this might be examined into by directing them to fome ftar fituated in, or very near, the ecliptic, and taking its meridian altitudes at a time of the year when it is in quadrature with the fun, in which cafe it would have no aberration. But either in this way, or with two feparate inftruments, the experiment might be made in a few nights, by taking the zenith diftance of a proper ftar, the plane of the inftruments being alternately turned different ways in obferving, to get the true zenith diftance independent of the error of the line of collimation; or the meridian altitude of the pole ftar may be obferved in December above and below the pole, which will give the apparent diftance of the ftar from the pole at that time as affected by aberration. The error of the line of collimation would not affect the refult in this way, being the fame in the obfervation both above and below the pole.
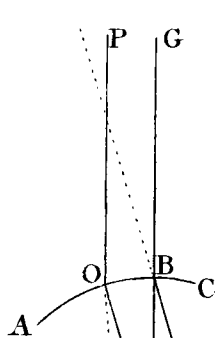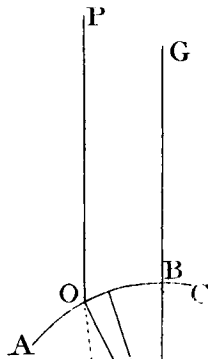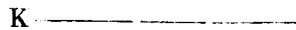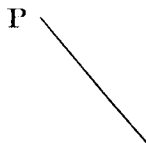
I   G   P G

L O B   O   B

A   C   A   C   A

M   M

Q

Fig. 1.   *Fig. 2*

F   E   D   H   F   E   D

P   G   P   G   P

O   B   B
        C   O   C
A   A

       M   M

Fig. 2   Fig. 3

                                              K

H   F   E   D   F   E   D

P

C

S

B

Fig. 1

Z

T

I

K

F   R

W   D

E   D